Marine Wind Retrieval in Non-Precipitating Regions Using Synthetic Aperture Radar

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Forecasts that are made using the Global Environmental Multiscale (GEM) model are produced operationally at the Canadian Meteorological Centre on a 15-km grid and even higher resolution regional runs are being examined. Such forecasts contain small-scale wind features that appear realistic, but evaluating the accuracy with which these features can be modeled and predicted with in situ observations would be prohibitively expensive. Advanced observational platforms, such as Radarsat-1, provide a high resolution reference. However, the backscatter cross section from this synthetic aperture radar (SAR) depends not only on the wind field, but on other physical processes as well. In order to evaluate a model forecast, it is necessary to gauge the accuracy of the SAR data and the marine winds derived from them.

Errors in SAR and GEM data can be explicitly considered from a regression perspective. The regression equations for SAR backscatter cross section ($\mathbf{y}$) and the GEM zonal and meridional wind components ($\mathbf{x}^\mathbf{b}$) can be written (in column matrix form) as

$$\mathbf{y} = \alpha^{-1}[CMOD(\mathbf{x}) + \mathbf{e}_\mathbf{y}]$$
$$\mathbf{x}^\mathbf{b} = \mathbf{x} + \mathbf{e}_\mathbf{x}$$

where the errors are $\mathbf{e}_y$ and $\mathbf{e}_x$ and $\mathbf{x}$ denotes the wind field to be estimated. The parameter a depends linearly on incidence angle and permits bias in multi-beam SAR acquisitions (cf. Vachon et al 1997) to be accounted for. The CMOD operator defines an empirical relationship between the wind field and the radar cross section (Hersbach 2003). It is a function of the SAR beam incidence angle, wind speed, and wind direction (relative to the satellite look angle). This relationship has been tuned using the ERS C-band scatterometers, whose polarization is vertical for send and receive. Because the Radarsat SAR polarization is horizontal, we include a polarization correction following Vachon and Dobson (2000). SAR observation errors (both radiometric and geometric, with the latter including errors in incidence angle) are resolved in the $\mathbf{e}_y$ term, as are errors in CMOD and its polarization correction.

The regression equations are nonlinear owing to CMOD. Following Dowd et al. (2001), we derive from the regression equations a nonlinear cost function

$$J(\mathbf{R},\mathbf{x}) = ln|\mathbf{R}| + [CMOD(\mathbf{x}) - a\tilde{\mathbf{y}}]^\mathbf{T}\,\mathbf{R}^{-1}[CMOD(\mathbf{x}) - a\tilde{\mathbf{y}}] + ln|\mathbf{B}| + [\mathbf{x} - \mathbf{x}^\mathbf{b}]^\mathbf{T}\mathbf{B}^{-1}[\mathbf{x} - \mathbf{x}^\mathbf{b}]$$

which assumes a log likelihood form for the errors. Here, the $\mathbf{R}$ and $\mathbf{B}$ matrices are the error covariance matrices of the SAR observations and the model winds, respectively. The two terms on the rhs involving $\mathbf{x}$ are measures of the variance of the SAR and GEM errors, respectively (Seber and Wild 1989). The tilde over the SAR observations indicates that we have removed the incidence angle dependence of these data using CMOD. This allows $\mathbf{R}$ to be positive definite. The cost function J is generally a function of the estimated winds (**x**) and the *unknown* error covariances (**R** and **B**). We assume that these decay exponentially with a length scale of 150 km and **B** error variances are fixed at 1 m^2/s^2 (i.e., only **R** varies).

We employ 609 SAR acquisitions from June 2004 to July 2005 at 6.4-km resolution and interpolate the 15-km GEM model wind and precipitation forecasts to this resolution. (A forecast spinup of at least 6 hours is allowed first.) Ship and buoy observations within 90 minutes and 50 km of these acquisitions are used to validate the resulting wind fields. If the SAR observations are used to validate the retrieved SAR backscatter, then we find a bias of 0.3 dB in both the GEM and retrieved errors. There is also a reduction in the corresponding standard deviation from 1.49 dB (GEM) to 1.33 dB (retrieved), which is to be expected. The independent comparison in terms of wind speed and direction employs the ship and buoy winds, but little evidence is found for reductions in bias and standard deviation. Improved representations of **R** and **B** are being examined.

Distinctions between regions with and without precipitation (according to the GEM forecasts) and between SAR data taken at low and high incidence angles have also been examined. Triple collocations (where SAR, GEM, and in situ data are all valid) that contain precipitation are found to have slightly higher wind speed error standard deviation than collocations without precipitation (3.4 m/s versus 2.1 m/s; however, note that the precipitation regions also have slightly stronger wind speeds). Triple collocations with no precipitation and low incidence-angle SAR data are also found to have higher wind speed error standard deviation than for the high incidence-angle collocations (2.5 m/s versus 2.2 m/s, respectively). These results indicate that a 2D-variational approach to quantifying SAR (and GEM) errors is instructive. They also suggest how improvements in the **R** and **B** error covariance matrices might be made.

References

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